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Technical Note

Influence of glass curtain walls on the building thermal energy consumption under Tunisian climatic conditions: The case of administrative buildings

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Abstract

The glass curtain walls have been recently introduced in Tunisia; they are seen as a new fashion and are highly appreciated by some for their pleasing aesthetics. The objective of this paper is to investigate whether the glass curtain walls are appropriate for the Tunisian local climate and context and if it is so, to give recommendations concerning the kind of glass to be used.

A TRNSYS [Klein SA. TRNSYS a transient system simulation Program V5 14.2. Solar Energy Laboratory, University of Wisconsin Madison, July 1996] simulation was conducted on a typical administrative building. The investigation concerns only the building heating and cooling load. The building was split in five thermal zones; for each thermal zone, all the windows have the same orientation. The single zone model TYPE19 of TRNSYS [Klein, 1996] was used to model each thermal zone. An additional convection heat transfer between the different thermal zones of the building was modelled according to the Brown and Solvason law [Brown WG, Solvason KR. Natural convection through rectangular openings in partitions, Part 1: vertical partitions. Int. J. Heat Mass Transfer 1962; 5: 859–68]. This particular law was used because it has been validated in the Tunisian context by Bouden [Bouden C. Analyse du suivi thermique d'un pavillon solaire expérimental en région Tunisoise, Thèse de doctorat, Université de Paris 7, 1989]. We assume that the glass curtain wall will be implemented only on the main building facade; this is why it was simulated with different glazing sizes and glass types. The other facades remain unchanged. The results of this simulation have shown that, in relation to space heating, the glass curtain wall can be very interesting in the Tunisian context if the orientation as well as the kind of glazing are carefully selected.

Keywords: Glass curtain wall; Passive solar gains; Administrative building

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Nomenclature:

A_j	overall surface of wall exposed to inside of zone
A_w	The window surface area
C	a constant equal to 0.78 for air at 20 °C
Cap	the effective capacitance of room air plus any mass considered with transfer functions (this mass is considered to be lumped)
g	The gravitational acceleration
h	The opening height
H	The wall height
$h_{c,j}$	convection heat transfer coefficient from wall j
$I_{\mathrm{b,T}}$	beam solar radiation on window
Q_{inf}	rate of energy transfer due to infiltration
Q_{int}	the rate of heat transfer due to internal sources other than people or light
Q_{n}	The net rate of heat transfer through the window
$Q_{\mathrm{s,p}}$	rate of energy transfer due to sensible gains from people
Q_{t}	the conduction rate of heat transfer through the window
Q_{v}	rate of energy transfer due to ventilation flow stream
Q_{Z}	the rate of heat transfer to the zone due to attached zones
T_{a}	the outdoor ambient temperature
$T_{\mathrm{R},j}$	the temperature of attached zone
$T_{\mathrm{s},j}$	Surface temperature of wall j
T_{Z}	the average room zone temperature
U_{A}	additional conductance for heat transfer between attached zones
U_{w}	The heat transfer coefficient through the window
w	The opening width
W	The wall width
ρ, C_p	respectively the air density and the air specific heat
τ_{b}	the glass transmittance to beam solar radiation, as function of the angle of incidence θ

1. Introduction

In Tunisia, winter is mild and humid, the outdoor temperature gap between day and night can be as high as 10–12 °C, and the daily average horizontal solar radiation is about 2700 Wh/m^2. Depending on the regions, the temperature during the day can fall down to 6 °C while the relative humidity can be very high and so, there is a real need for heating. In Summer, the outdoor temperature gap between day and night can exceed 15 °C and the daily horizontal global solar radiation is around 6350 Wh/m^2. The peak outdoor temperature can exceed 40 °C during some days in Summer [1,2]. The Summer relative humidity is very different from one region to the other; it can be very high nearby the costs and very low in the continental regions. Such climate needs heating in Winter and cooling in Summer. Fig. 1 shows the monthly maximum, minimum, and average temperature and the monthly average global horizontal solar radiation for the city of Tunis.

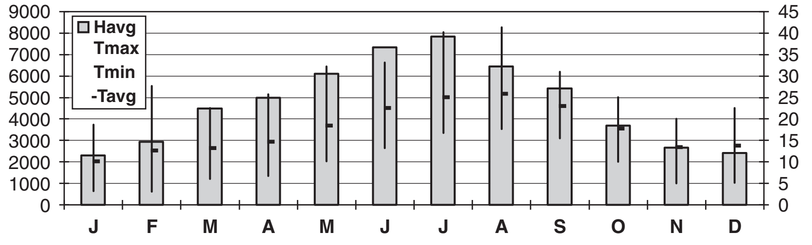

Fig. 1. Monthly average solar radition (Wh/m2) (left axis) and monthly minimum, maximum and average temperatures (°C) (right axis).

Traditionally, man has adapted his activity and his building techniques to the climate. The traditional Tunisian buildings are characterized by very high thermal capacity, small exterior openings, shadowing devices, narrow streets, etc. Occupant's activity has also been adapted to the climate: only one working shift is programmed in Summer, it starts at 7:00 am and ends at 2:00 pm. People are used to taking a nap after lunch and having a long evening outside to enjoy the evening fresh air. Nowadays, all these behaviours and traditions are becoming less and less frequent because of the modern style of life. Modern bricks, concrete, steel and glazed buildings are replacing the traditional medina highly massive dwellings. The Summer working hours are extended during the whole day. People have more productive activities during the evenings and so they need a more comfortable indoor temperature. All these new facts have contributed to an ever increasing need to heating and cooling. Heating and cooling equipment is installed systematically in the new buildings. The old dwellings are also being equipped progressively with split-air-conditioning systems and with heating devices. The gap between the gas and electricity prices pushed the designers to adopt a gas central heating system in winter and electric chillers in Summer. The Summer air-conditioning energy consumption has changed the utility surge profile during the last few years. Recently, a new peak of consumption has appeared between 11 a.m. and 3 p.m. during the hot season.

The official energy consumption data [3] shows that the energy consumption growth in the building sector is much higher than the average growth for the total national energy consumption. Nowadays, the energy consumption for the building sector is occupying the third position behind the industry and the transportation sectors. The prospective previsions for the year 2020 are predicting that the building sector can be the first energy consumer in Tunisia. Table 1 shows the present data and the prospective for the year 2020. It also shows that the growing building sector is the highest among the four sectors of activity; this is partly due to the lack of thermal regulation for buildings.

For all these reasons, the National Energy Agency is working to establish a new building thermal standard. This standard has to take in consideration on one hand the climate specific characteristics, on the other hand the people behaviour and culture and also the modern architecture tendency and building practices.

A new trend in Tunisian construction is the use of the glass curtain walls. Recent research works [4,5] have shown that highly glazed facades, if designed carefully, can exhibit a significantly better behaviour than conventional windows. On the other hand, if they are poorly designed, they not only increase the building energy consumption, but also affect the occupants' thermal comfort, due to the thermal radiation coming from the hot

Table 1
Energy consumption and trends in Tunisia [4]

Activity	Energy Consumption (kton)								Growth factor		
	1992	(%)	2001	(%)	2010	(%)	2020	(%)	92–01	01–10	10–20
Industry	1388	37	1861	35	2712	30	3664	27	1.34	1.95	2.64
Transportation	1139	31	1681	32	2879	32	4301	31	1.48	2.53	3.78
building	902	24	1338	26	2829	32	4991	36	1.48	3.14	5.54
Agriculture	280	8	365	7	549	6	719	5	1.31	1.96	2.57
Total	3708	100	5245	100	8969	100	1367	100	1.41	2.42	3.69

glazing surfaces. Manz [6] has shown that for double glazed facades, the air gap temperature between the two glass panes can reach temperatures as high as 80 °C and hence the interior thermal comfort decreases because of the thermal radiation caused by the glazing.

New kinds of glass materials and coatings [7,8] can provide the appropriate shading and protect against overheating during the hot season. Such intelligent glazing can reduce the thermal energy consumption during Summer, they can be appropriate in the Tunisian and perhaps more widely in the Mediterranean climatic conditions.

The use of glass curtain walls is not only a matter of fashion and aesthetics, but, if well designed, it can contribute to rationalizing the lighting energy consumption of the adjacent spaces. Inoue [7] and Sadar et al. [9] have shown that an appropriate use of glass provides large total energy savings through an efficient use of natural lighting.

This paper aims to study the appropriate fraction of glazed facade and give some simulation data and results; these data can help for the selection of the most appropriate kind of glass for the Tunisian context from the heating and cooling angle.

2. Methodological approach

2.1. Context of the study

So far, there has been no thermal standard in Tunisia; people can build without any restrictions. The application of thermal insulation in the walls and roofs is seldom if ever used. As a consequence to the lack of thermal standard, the building sector is becoming one of the most energy consuming.

The studies aiming to create a thermal standard for buildings started in 1993. During the first step, an inventory of the traditional and current buildings typology was prepared and a list of the available building materials and systems used for wall and roof construction was established. This list included the thermal properties of each wall layer.

In a second step, the country was split in three climatic zones. The data were collected for each zone. A full year of meteorological data was identified for the region of Tunis as the most likely representative for the climate of this regin. For the two other climatic zones, the available meteorological data records were not sufficient to establish a TMY[1] for each of them because most of the meteorological stations are recent; this is why, for each

[1]TMY: Typical meteorological year

climatic zone, 12 typical meteorological periods of 10 days, each corresponds to a month of the year, were elaborated.

During the third step, simulations using the TRNSYS program were performed in order to evaluate the quality of the thermal comfort and calculate the energy consumption of the buildings for each wall composition.

The fourth step concerned the optimization of the envelope materials from the thermal and economical point of view in order to improve the thermal comfort and reduce the energy consumption. During this step, each of the currently used envelope composition was simulated in its present configuration, then improvements were introduced (introduction of thermal insulation, thickness and position of the thermal insulation, optimization of the thermal mass position and value, etc.). The over-cost caused by the introduction of these measures must not exceed 10% of the present envelope cost.

The current step of the study concerns the administrative and service buildings. Similar simulations to those performed for the residential dwellings are being carried out for the administration and service buildings. The results of these simulations are different from those for the residential buildings because of the different occupation schedules and internal heat gains. In most cases, the administrative buildings are having a lower thermal mass and their ventilation rate is higher than that of residential buildings.

The recent administrative buildings are equipped with large glazed facades which may contribute to decreasing the heating energy consumption in winter but can largely increase the cooling energy consumption in Summer if the kind of glass is not carefully chosen. Highly glazed facades can be aesthetically pleasing to some and offer a higher visual comfort because of the better natural lighting.

The objectives of this work are to compare, under the Tunisian climatic conditions, the thermal performances of a building when different kinds of glazing at different sizes are used. The most appropriate kind of glazing has to be selected and the ratio between the glazed surface and the overall wall surface has to be optimized.

An administrative building was modelled and simulated using the TRNSYS simulation program [10]. Hourly simulations were conducted over a 1 year period using the meteorological data of Tunis, and the daily building thermal energy consumption was calculated.

The simulation results were processed and analysed. Data concerning the percentage of glazed surface and the kind of glazing to be adopted are presented.

2.2. The building description

A study has shown that more than 70% of the administrative buildings in Tunis have an L or a U shape. All the buildings in the old town have no more than four stories, while in the new town districts, the number of stories can be higher. For these reasons, we decided to focus our study on the case of L shaped four storey buildings.

An administrative four storey building with a large main facade was used for the simulations. The floor surface area is 342 m^2 and the total building area is 1370 m^2 among which 1015 m^2 is heated and cooled, which corresponds to a total volume of 2840 m^3. Fig. 2 gives a drawing of the building and its thermal zones.

The building main facade surface area is 262 m^2. This façade was simulated with different glazing sizes starting from a ratio of glazed surface to total wall surface equal to 20% (this is the most commonly used ratio in Tunisia for administrative buildings) to a

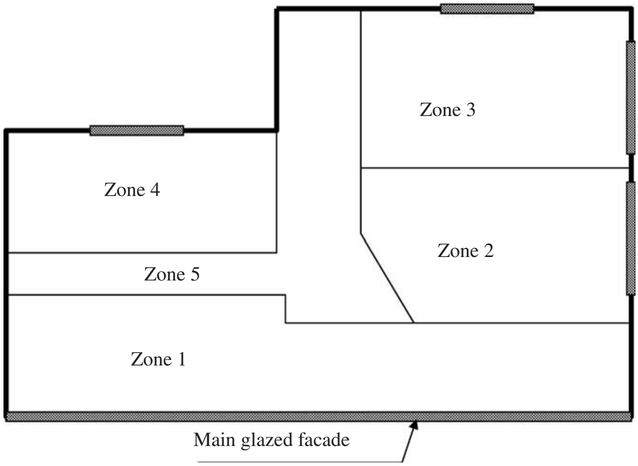

Fig. 2. The building thermal zones.

ratio of glazed surface to a total surface equal to 90%, which represents a glass curtain wall.

The most commonly used wall composition in Tunisia is made of two brick layers separated by an air gap. The introduction of a layer of thermal insulation material can be considered as an improvement of this wall. The studies which were carried out within the frame of the standard for residential buildings have shown that for free running temperature buildings, it is very interesting to isolate the roofs but not the walls particularly in Summer [13]. This is because most of the Tunisian buildings have a high thermal mass and so the walls can store heat. In Summer, during the night, the wall thermal mass is cooled naturally by the ambient air. The freshness is stored in the wall for the next day. If the wall is equipped with a thermal insulating material layer, the cooling process does not take place appropriately and the thermal mass which is inside the thermal insulation will store the heat for the next day. For air-conditioned buildings, a thermal insulation can help to reduce the heating and cooling energy consumption. On the other hand, for the Tunisian standard, it was decided to introduce improvements for which the over cost, in comparison to the common way of construction, cannot exceed 10% of the current price of the walls, such improvement means for example the introduction of a thermal insulating layer. To fit with the cost restrictions, the thickness of the thermal insulating material cannot exceed 50 mm. The introduction of 50 mm of thermal insulating material is a very innovative measure for the Tunisian context because, up to now, it is not common to insulate buildings. A thicker layer will not introduce a significant improvement from the thermal angle due to the mildness of the climate. It will have a long pay back period, and so cannot be justified from the economical angle.

The building common walls are made of two 100 mm brick layers separated by 50 mm of thermal insulating material in the middle, the wall overall U value is $0.63\,\mathrm{W/m^2\,K}$. The roof is made of 150 mm heavy concrete deck and a layer of 50 mm made of thermal insulating material. The roof U-value is equal to $0.66\,\mathrm{W/m^2\,K}$.

The building can be considered as a high thermal capacity building because of the mass of the different floors and walls. The windows are not equipped with shutters or night insulation system which is common for administrative buildings in which only interior venetian blinds are installed as protection against direct solar radiation.

2.3. The building model

According to the windows orientations and the space functional allocation, the building has been divided into five thermal zones:

1. Zone 1: has the main building facade directed towards the South. A ratio of 43% of this facade is glazed. The facade is proposed to be moved to a curtain glass wall. The floor surface area of this zone is 130 m^2.
2. Zone 2 windows are directed towards the East. The floor area of this zone is 34 m^2 and the windows' surface area is 20.7 m^2.
3. Zone 3 windows are oriented to North and to East. The floor area of this zone is 46 m^2 and the windows' areas are, respectively, 34 and 20 m^2.
4. Zone 4 windows are facing to North. The floor area of this zone is 44 m^2 and the windows' area is 34 m^2.
5. Zone 5 is composed of the main building hall, the central courtyard, the stairs and the elevators area. The under roof height of this zone is equal to four stories without any separation or intermediate floor, which corresponds to 12 m. This zone communicates with all the others. It is not air-conditioned and so its temperature is free running. The floor surface area of this zone is 88 m^2.

Fig. 2 Shows the zone repartition and the windows position. For zones 1–4, the set temperature for heating was settled on 19 °C and the set temperature for cooling was settled on 26 °C.

The building ventilation is provided mechanically through the air-conditioning system. For each controlled thermal zone, the ventilation rate is considered to be equal to 0.5 vol./h during the night and 1 vol./h during the working hours. Zone 5 corresponding to the building main hall includes the lobby and the main entrance. The ventilation rate is considered to be 5 vol./hour during the working hours and 0.5 Vol./h during the night. The daily diurnal high rate air change simulates the frequent openings of the building main door since it is not common to find any system for energy conservation in the building entrances.

Each thermal zone has been described using TYPE19 of TRNSYS model. This program uses the response factors method to calculate the heat transfer through the walls.

The energy balance on the zone air plus the furnishings is given by

$$Cap\frac{\mathrm{d}T_Z}{\mathrm{d}t} = \sum_{j=1}^{N}\left[h_{c,j}A_j\left(T_{s,j} - T_Z\right)\right] + Q_V + Q_{inf} + Q_{int} + 0.3Q_{s,p} + Q_Z, \quad (1)$$

Q_Z is an additional convection heat transfer which occurs between two adjacent zones through the doors and openings. This heat transfer is calculated according to the empirical Brown and Solvason law [11] given by the following expression:

$$Q_Z = U\ A\,\Delta T, \quad (2)$$

where A is the opening surface area, ΔT the temperature difference between the adjacent zones $= (T_Z - T_{R,j})$, Q_Z the rate of convection heat transfer to the zone due to attached zones (W), U is the convection overall heat transfer coefficient given by

$$U = \rho c_p \frac{C}{3} \frac{w}{W} \left(\frac{h}{H}\right)^{3/2} \sqrt{gH\left(\frac{\Delta T}{T}\right)} \tag{3}$$

The wall surface temperatures are calculated according to the response factors method detailed by Madsen [10,12].

Diffuse radiation entering windows is assumed to be isotropic. Direct solar radiation is assumed to strike on several fixed surfaces. Radiation gains from light, people and solar radiation entering through windows are assumed to be diffusely reflected.

The windows are supposed to transmit both direct ($Q_{b,s}$) and diffuse ($Q_{d,s}$) solar radiation striking on their respective surfaces according to

$$Q_{b,s} = A_W \tau_b I_{b,T}, \tag{4}$$

$$Q_{d,s} = A_W \tau_d I_{d,T}, \tag{5}$$

where τ_b,τ_d, are respectively, the glass transmittance to beam and diffuse solar radiation; $I_{b,T}$,$I_{d,T}$, respectively, the beam solar radiation and the diffuse plus reflected solar radiation incident on the window surface; and A_W is the window surface area.

The transmittance of diffuse and ground reflected radiation is considered to be equal to the transmittance of beam radiation incident at angle of 60°.

The conduction rate of heat transfer through the window is given by

$$Q_t = U_W A_W (T_a - T_Z), \tag{6}$$

The net rate of energy transfer across the window is given by

$$Q_n = Q_{b,s} + Q_{d,s} + Q_t. \tag{7}$$

2.4. The building simulations

The building was simulated at its actual configuration according to the architect drawings. Then, a number of modifications were operated to study their impact on the building energy balance. A first set of simulations concerned the facade window sizes; the following configurations were studied:

1. Normal Windows sizes: 20% of the facade is glazed, which represents the most currently used architecture.
2. Slightly large windows: 45% of the façade is glazed (actual configuration).
3. Large windows: 60% of the façade is glazed.
4. Very large windows: 70% of the façade is glazed.
5. Glazed curtain wall: 90% of the façade is glazed. (The remaining 10% are for the frames and the building structure).

The building was simulated using seven different kinds of glazing. The different kinds of glass used during the simulations are summarized in Table 2. The different sizes of the faç ade window were studied for the different kinds of glass described in Table 2.

Table 2
Different kinds of glass used in the simulation. The transmittivity to diffuse solar radiation is considered to be equal to $\tau_d = 0.6 \times \tau_b$

Reference	Description	τ_b	U_w(W/m^2 K)
G1	Single glazing, clear glass	0.87	5.8
G2	Single glazing, stained glass (green)	0.64	5.8
G3	Double clear glass panes + air gap: 4 mm + air gap of 12 mm + 4 mm	0.78	2.9
G4	Double glazing: clear glass + air gap + stained glass: 4 mm + 12 mm + 4 mm	0.54	2.9
G5	Double glazing: clear glass + air gap + reflecting glass: 4 mm + 12 mm + 4 mm	0.12	2.3
G6	Double glazing: clear glass + air gap + low E glass: 4 mm + 12 mm + 4 mm	0.64	1.7
G7	Double glazing: clear glass + argon gap + low E glass: 4 mm + 16 mm + 4 mm	0.64	1.1

Table 3
Different simulation cases where AAGIO the nomenclature for the different simulations cases is as follows:

AA	Two digits to indicate the rate of the glazed surface as a percentage of the total façade area. It takes one of the following values: 20, 45, 60, 70 and 90 corresponding, respectively, to a ratio of the window area to the total façade area equal to: 20%, 45%, 60%, 70% and 90%.
GI	Two digits to indicate the glass type according to what is indicated in Table 2. It can take one value among seven: G1, G2, G3, G4, G5, G6, G7
O	One digit to indicate the main facade orientation. It can take one of the four values: E for East, S for South, W for West and N for North

Since the glass curtain wall concerns only the main façade of the building, only the "Zone 1" main façade window area was changed during the simulation, the other building windows were preserved at their standard sizes. On the other hand, during one simulation, all the building windows are of the same type and have the same kind of glazing. The building performances were investigated for four different orientations of the main facade: South, West, East and North. The building thermal energy consumptions were compared for all these orientations and for the combinations of the 7 different kinds of glazing and the five ratios of glazed area to wall area. The different simulation cases are summarized in Table 3.

The simulations were conducted hourly during 1 year. The hourly temperatures for each thermal zone were calculated. For each thermal zone, the daily cooling and heating energy consumption and the total building energy consumption were calculated, integration along the year was done to calculate the yearly energy consumption.

3. Results and discussions

3.1. Influence of the orientation on the reference building

Simulations have shown that for zone 1 (including the main façade of the building), the best orientation in Summer is when its windows are facing North; it is followed by West and South. The East orientation is the most energy consuming in Summer. In winter, the best orientation is obtained when windows are facing south; it is followed by East, West and North. The yearly energy consumption is the lowest when the building is directed towards the south. It is followed by the North, then West; the East is the most Energy consuming orientation. This result comes from the fact that the North orientation is the best in Summer. Due to the solar gains, when facing the south the building has the maximum cooling energy consumption in Summer and the minimum heating energy consumption in winter and when it is facing North, the cooling energy consumption becomes minimum and the heating energy consumption becomes maximum. Since both energy consumptions are comparable, the yearly performances of those two orientations are very close to each other. Fig. 3 shows the yearly heating and cooling energy consumptions for zone 1 and Fig. 4 shows the yearly heating and cooling energy consumptions for the whole building.

3.2. Influence of window sizes and introduction of the glass curtain wall

When the kind of glass is kept unchanged (single glazing, type G1) and the fraction of the glazed surface area to the total main facade wall surface area is changed, the observation of the hourly temperatures shows that for a glazed ratio corresponding to 45% (or higher) of the total area of the south façade, the temperature in zone 1 fluctuates between the set point of heating and the set point of cooling. This means that the direct

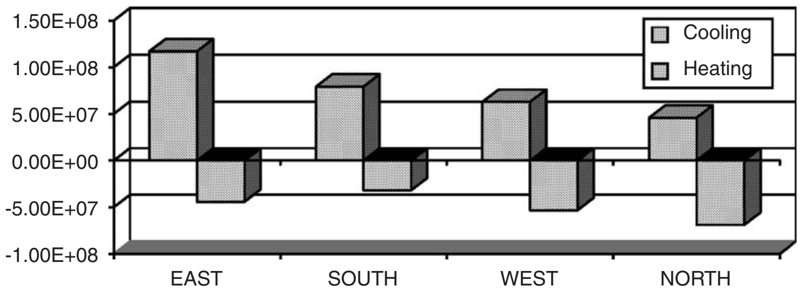

Fig. 3. Yearly total heating and cooling energy consumptions for zone 1.

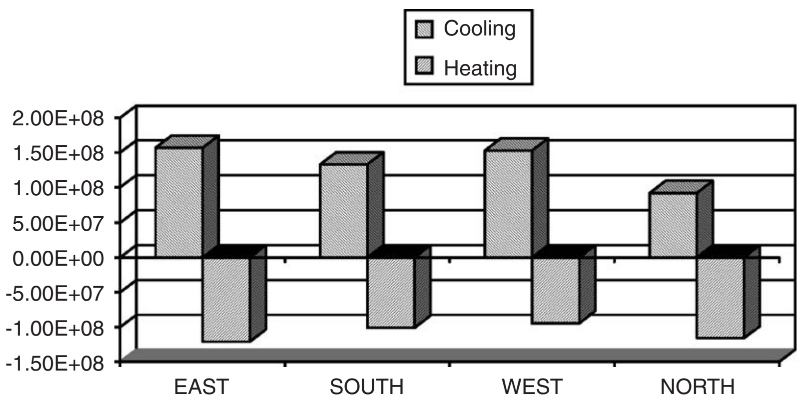

Fig. 4. Yearly heating and cooling energy consumptions for the whole building.

solar gains are important and a distribution system of these gains among the different zones has to be well designed. The unconditioned zone temperature (zone 5) was fluctuating between day and night and from season to season. This zone temperature is nearly following the exterior ambient temperature with some dumping. These fluctuations are due to the fact that this zone is opened directly to the ambient air since the main building entrance is located in this zone. A heat recovery or any system for energy conservation has to be designed at the main entrance to reduce the heat losses due to the air change in this zone. (Table 4–6)

When the glazed surface increases, we notice that the energy consumption also increases in Summer as well as in winter. This is because from one side the U-value of the single glazing is very high and from the other side, the windows are not equipped with shutters for the cold winter nights, so during the winter days, the building harvests a high amount of solar energy, but the night thermal losses increase considerably in ratio to the glazed surface area. Fig. 5 shows the yearly heating and cooling energy consumptions for the whole building when a single glazing is used. Fig. 7 shows a comparison between the yearly overall energy consumptions corresponding to four different kinds of glazing. The ratio of glazed area to total area of the main façade has been simulated for the values of 20%, 45%, 60%, 70% and 90%. We can notice that the increase of the window surface will be

Table 4
Total yearly energy consumption (MJ/m^2) of the whole building: comparison between different wall configurations

Glass type	Percentage of glazed surface in the main façade (%)	Total energy consumption (MJ/m^2)		
		Summer	Winter	Year
Single, clear (G1) (reference case)	20	106.4	95.4	201.8
Double, 2 clear (G3)	90	170.4	65.1	235.5
Double: 1 clear + 1 stained (G4)	90	102.5	86.7	189.2
Double : 1 clear + 1 reflecting (G5)	90	42.7	125.1	167.8
Double : 1 clear + 1 low Emissivity (G6)	90	137.9	53.1	191.0
Double : 1 clear + 1 low emissivity + argon gap (G7)	90	145.8	43.1	188.9

Table 5
Summer cooling energy consumption (MJ/m^2) for different window-sizes, the window size is considered in percentage of the total wall surface area

Percentage of glazing	Glass type	Summer cooling energy consumption (MJ/m^2)	
20% glazed wall	G1: Single clear glass (reference)	106.4	
90% glazed wall	G1: Single clear glass	172.4	+62%
20% glazed wall	G5: Double glazing (1 clear + 1 reflecting)	38.9	−63%
90% glazed wall	G5: Double glazing (1 clear + 1 reflecting)	42.7	−59%
20% glazed wall	G7: Double glazing (1 clear + 1 low E + Argon)	83.5	−21%
90% glazed wall	G7: Double glazing (1 clear + 1 low E + Argon)	145.8	+37%

Table 6
The total building energy consumption (MJ/m^2) when the glass curtain wall is made of (1) low Emissivity glass (Glass type G7) compared to the variant version of two reflecting glass (glass type G5) for different orientation of the main facade

Main façade orientation	Low emissivity glass (G7)		Reflecting glass (G5)	
	Heating energy consumption (MJ/m^2)	Cooling Energy consumption (MJ/m^2)	Heating energy consumption (MJ/m^2)	Cooling Energy consumption (MJ/m^2)
South	43.2	145.8	125.1	42.7
West	40.9	150.0	125.0	39.1
North	52.3	86.3	137.0	33.2
East	55.7	193.0	136.0	40.5

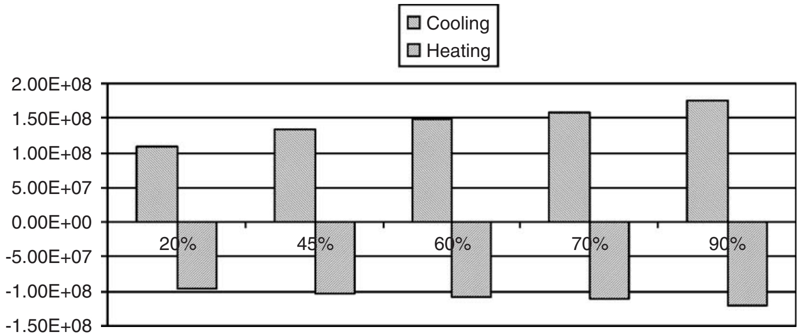

Fig. 5. Yearly heating and cooling energy consumptions for the whole building corresponding to different rates of glazed area in the south facade. A single glazing is used.

accompanied by an increase of the conduction heat transfer through the window and an increase of the solar gains, this leads to a rise of the thermal energy consumption in both seasons.

3.3. Influence of the kind of glass

The building has been simulated with seven different kinds of glazing (G1–G7 according to what is described in Table 2).

The reference building is equipped with single clear glazing; 20% of its main façade is glazed. This configuration corresponds to the most currently used configuration for administrative buildings in Tunisia.

In this part, we will focus on the energy consumption of a modified building equipped with a glass curtain wall (90% of the main façade is glazed) and we will compare the building energy consumption of the reference building to those of the variant versions when equipped with different kinds of glass (G1–G7) (Fig. 6).

Fig. 7 shows a comparison between four kinds of glass. We can notice that for all these kinds of glass, the more the percentage of glazed surface in the main facade increases, the higher the yearly energy consumption is; however, we can observe that when the building is

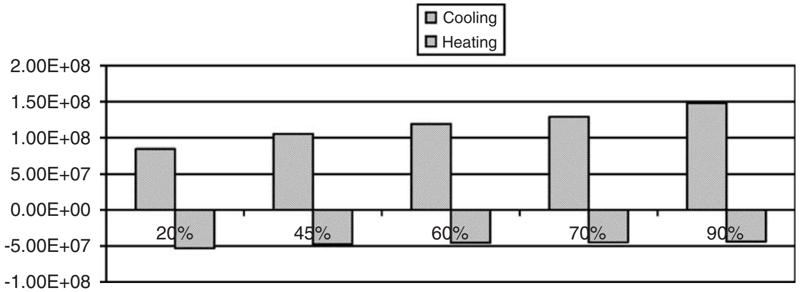

Fig. 6. Yearly heating and cooling energy consumptions for the whole building corresponding to different rates of glazed area in the south facade. A double glazing is used: one clear + one low emissivity (type G7 according to Table 2).

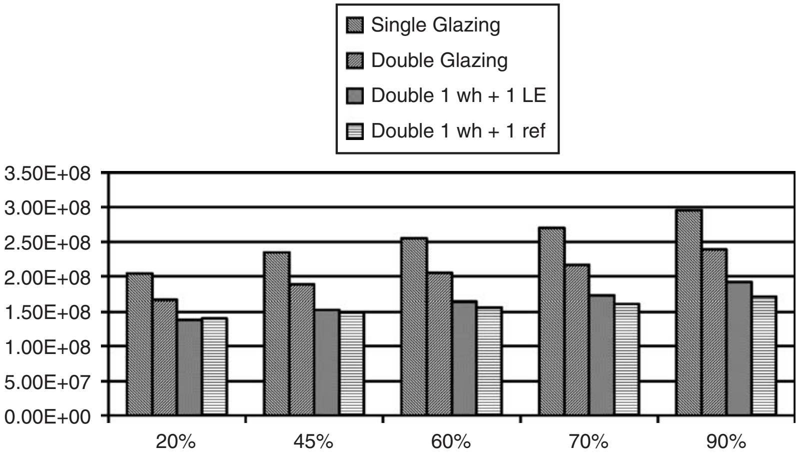

Fig. 7. Overall energy consumption (kJ) for the whole building corresponding to different rates of glazed area in the south facade. Comparison between single glazing (clear glass: type G1), double glazing (clear glass: type G3), a double glazing (one clear + one low emissivity: type G7) and a double glazing (one clear + one reflecting: type G5).

equipped with a glass curtain wall of type G5, G6 or G7, it has a lower overall yearly energy consumption, than that of the reference building; this is because the U values of these latter kinds of glass are much lower than that of a single glazing (G1).

Table 7 shows the building seasonal energy consumption when reflecting glass or low emissivity glass are used at different proportions of the main facade surface. We can notice that when increasing the percentage of glazed surface, the energy consumption increases in winter as well as in Summer for the case of G5 glass (one reflecting and one white). For the low emissivity (G7), when the percentage of glazed surface increases, the winter energy consumption decreases, but the Summer consumption increases. The overall yearly energy consumption for those two kinds of glass are comparable with differences lower than 12%.

The U-value of the low emissivity glass (G7) ($U_{\text{window}} = 1.1\,\text{W/m}^2\,\text{K}$) is very low in comparison to the other kinds of glass. It can be considered close to that of the masonry wall ($U_{\text{wall}} = 0.63\,\text{W/m}^2\,\text{K}$), so, for this specific kind of glass, the glass curtain wall insulates slightly less than a blind masonry wall, but has the advantage of harvesting solar

Table 7
Total yearly energy consumption of the whole building: comparison between different wall configurations

Percentage of glazed surface in the main facade	Total energy consumption for reflecting glass (G5) (MJ/m^2)			Total energy consumption for low-e glass (G7) (MJ/m^2)		
	Summer	Winter	Year	Summer	Winter	Year
20% (reference case)	38.9	99.5	138	83.5	52.5	136
45%	40.4	106.6	148	103.4	46.6	150
60%	41.2	112.8	154	117.2	44.8	162
70%	41.7	117.3	159	127.0	44.0	171
90%	42.8	125.2	168	145.8	43.2	189

radiation during the cold winter days, which decreases the thermal energy consumption in winter. The solar gains compensate the surplus thermal losses and the overall balance of the window is better than that of the masonry wall. Fig. 6 shows the yearly energy consumption for heating and cooling for a double glazing, the first is a clear glass and the second is a low emissivity glass with argon gap (type G7 according to Table 2 indications).

When a reflecting glass (type G5: one clear and one reflecting) is used, the Summer cooling energy consumption is as low as 4.3E7 kJ (which corresponds to 42.2 MJ/m^2). This amount of energy accounts for 24.6% of what a single glazing would have consumed: for the type G1 glass curtain wall, the cooling energy consumption is equal to 17.5E7 kJ (which corresponds to 172.4 MJ/m^2).

Table 5 Summarizes the summer cooling energy consumption (in MJ/m^2 of a heated area) for two different window sizes. The widow size is considered to be, respectively, 20% and 90% of the total wall surface area. The difference of yearly energy consumption between 20% glazed wall and 90% glazed wall is as low as 10% when a double glazing (G5: 1 reflecting + 1 clear) is used.

Table 4 shows that the winter thermal energy consumption of the building when equipped with a curtain reflecting glass-wall is twice as high as in the case when it has a low emissivity glazing, but the annual overall consumption is comparable for these two kinds of glass. The simulation results have shown that double glazing with either low emissivity (G6 or G7) or reflecting glass (G5) are performing very well. The yearly performances are very close but the reflecting glass gives a much better thermal comfort in summer and avoids dazzling for the occupants.

The results of the simulation show that, if the kind of glass is very well chosen, a glass curtain wall can perform better than the currently used way of building (our reference case: brick wall with 20% of single glazed window). It is worth using glass curtain walls with smart glass (reflecting or low emissivity) because they are less energy consuming than the commonly used architecture and are aesthetically more pleasing than the conventional brick walls. A building equipped with a double clear glass curtain wall consumes for heating and cooling 10% more energy than a similar building equipped with a masonry wall with 20% double glazed window (reference case).

3.4. Combined effect glass type-orientation

The orientation of the glass curtain wall with either low emissivity or reflecting glass has been investigated. The building has been simulated when the curtain wall is oriented to south, West, North and East for both kinds of glass. The energy consumption has been calculated during the heating season and during the cooling season. Table 6 summarizes the results of these simulations. For the reflecting glass (G5) the yearly overall performances are very close to each other independently of the orientation, this is because this kind of glass is reflecting the major part of the incident solar radiation, the west orientation shows a higher cooling energy consumption in Summer. The major energy consumption is in winter because the conduction heat transfer through the window is very high and the direct solar gains are very low.

For the low emissivity glass, the west orientation has the highest Summer and yearly thermal energy consumption. East and North orientations have high cooling energy consumption. The south orientation is the best since it has the lowest energy consumption over the year and the value of the cooling load is very close to the value of the heating load for a facade facing south.

The seasonal energy consumption for the whole building (Table 4) has shown that the glazing can be classified by decreasing performances as follows:

Winter conditions:

1. double: 1 clear + 1 low emissivity
2. double: 2 clear panes
3. double: 1 clear + 1 stained
4. Single clear pane
5. double: 1 clear + 1 reflecting
6. Single: stained

Summer conditions:

1. Double: 1 clear + 1 reflecting
2. Double: 1 clear + 1 stained
3. Double: 1 clear + 1 low emissivity
4. Double: 2 clear panes
5. Single: clear
6. Single: stained

For the overall yearly performances:

1. Double: 1 clear + 1 reflecting
2. Double: 1 clear + 1 low emissivity
3. Double: 1 clear + 1 stained
4. The single glazing is not recommended.

4. Conclusion

The simulation results have shown that glass curtain walls can be adopted in the case of administrative buildings in Tunisia. Such walls can perform better than a normal masonry wall with small windows covering 20% of the total wall area, if an appropriate kind of glazing is selected.

The seasonal energy consumption has shown that for the winter conditions, double glazing with one clear and one low emissivity filled with argon has the lowest energy consumption. In Summer, double glazing: one clear and one reflecting glass has the lowest energy consumption. On an annual basis, double glazing with one clear and one reflecting has the lowest energy consumption; it is followed by double glazing made of one clear and one low emissivity (G6 or G7).

For the reflecting glazing, the North, South and East orientations are nearly equivalent, The West orientation gives a slightly higher energy consumption in Summer, but we can neglect this difference and consider that the four orientations are equivalent if this kind of glazing is used. The building is insensible to the orientation because the glazing is reflecting the major part of the solar radiation, only the conduction heat transfer through the window is important.

For the low emissivity glazing, the south and North orientations have very close yearly behaviour. The North orientation has a much lower Summer energy consumption. The West orientation has the lowest yearly performances because it has the highest thermal energy consumption in Summer.

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